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A CRITIQUE OF ALLOWANCES FOR UNCERTAINTY IN ESTIMATING THE PRODUCTIVITY OF CAPITAL ON INDIVIDUAL INVESTMENTS

By

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Although the rate of return method of measuring the productivity of capital has been a feature of the industrial economics literature for some years now, little has been said about the problem of adjustment for uncertainty. In fact, one recent paper asserts that the absence of a satisfactory means of including uncertainty in the analysis is the most serious deficiency in capital budgeting at present (4). Existing procedures fall into one of four categories and in essence are rules of thumb (1,2). This paper is concerned with the effectiveness of these adjustments. It is shown that they do not perform in a very satisfactory manner, the primary difficulty being that the effect of the adjustment bears little relation to the adjustment itself. The results demonstrate the need for some techniques for handling uncertainty which will incorporate the uncertainty directly into the analysis of the problem, rather than treat it as an afterthought. At present, the wise course of action would appear to be to make no attempts to adjust.

THE MODEL FOR ANALYSIS

The rate of return method of measuring capital productivity of a project reduces the future cash flows of the project back to their present value. The present worth of a project is the

difference between the present value of the future cash flows and the cost of the project. Any salvage value is treated as a part of the future cash flow. This may be expressed in mathematical form (see Reference 3 for derivation) as:

$$W = \int_0^T [R(t) - E(t)]\, e^{-it} dt + S(T)e^{-iT} - C \qquad (1)$$

where
- W = present worth of return on investment
- $R(t)$ = revenue function
- $E(t)$ = expense function
- $R(t) - E(t)$ = net cash flow at time t
- i = rate of interest
- T = useful life of the investment
- $S(T)$ = salvage value at T
- C = installed cost of project.

This formula assumes that the flow of cash is continuous, and that it can be expressed by some sort of functional relationship with time. If this assumption is not acceptable, the present worth, W, must be represented by the sum of a series of discrete cash flows occurring in a number of time intervals. If the assumption of continuous cash flow can be made without introducing serious error, it is highly desirable to do so, since it greatly simplifies the arithmetic of the analysis. In practice, if the discrete time intervals are short, the error from assuming continuity is very small. For example, in the use of compound interest formulas the difference between weekly compounding and continuous compounding is less than 0.2%. It seems reasonable to assume that the cash flows generated by an investment will be spread out in a fairly smooth (but not necessarily level) manner over the life of the investment, rather than occurring in a few large lumps. If these assumptions are granted, the mathematical model of Equation (1) will be adequate for the analysis.

So that the effects of adjustments for uncertainty may be seen even more clearly, some additional simplifications will be made. It will be assumed that the salvage value is zero, and that all of the cost comes exactly at time zero. It is important to recognize that these are not necessary assumptions, but that they are made only to simplify and clarify. If the adjustments are not satisfactory in a highly simplified situation, they hardly can be expected to be adequate in a more realistic one.

The equation which is the basis for analysis is:

$$V = \int_0^T f(G)e^{-it}dt \qquad (2)$$

where
- V = present value
- i = rate of interest
- T = useful life of the investment
- $f(G)$ = function which describes the net cash flow
  $= R(t) - E(t)$

(Note that this is the first term of Equation (1). The other terms are either zero or constant according to the assumptions, and so are not relevant to this analysis.)

Two types of cash flow are to be considered. In Type 1 the function f(G) is a straight-line relationship and in Type 2 it is an exponential relationship. Type 1 can be represented as

$$f(G) = A + Bt$$

where
- A = initial cash flow
- B = rate of change of A with time
  (This is analogous to straight-line depreciation.)

Type 2 can be represented as

$$f(G) = Ae^{gt}$$

- A = initial cash flow
- g = rate of change of f(G)
  (This is analogous to declining-balance depreciation.)

The factors B and g may be positive, zero, or negative to represent respectively increasing, level, or decreasing cash flows.

THE EFFECT OF ADJUSTMENTS FOR UNCERTAINTY

There are four ways to allow for uncertainty which are used in practice (1,2):

1. Increase the interest rate.
2. Shorten the estimate of the useful life.
3. Apply a probability multiplier to the cash flow.
4. Informal judgment applied to the final results.

The first three are of interest here. The fourth amounts to an attempt to adjust by using a subjective probability to find the "best" estimate of the present worth. It has the advantage of being honest in the sense that it does not obscure the fact that it depends on judgment. It implies, however, that something other than the "best" estimates were used in the calculations. The first three methods tend to bury the judgment phase behind a mass of numbers.

The adjustments are made by changing the uncertainty factor by some amount, Δ, and computing a new value, V'. The investment decision is then made on the basis of V', which is supposed to be a value which has been corrected for the uncertainty, usually in a conservative direction. The interesting functions are the change in value, $\Delta V = V - V'$, and the relative change in value, $\Delta V/V$.

Three cases may be identified, corresponding to the three kinds of adjustment:

Case I	Apply an increment, Δi,	to i.	Δi usually positive.
Case II	Apply an increment, ΔT,	to T.	ΔT usually negative.
Case III	Apply an increment, ΔB / Δg)	to $\left(\frac{B}{g}\right.$. $\left.\frac{\Delta B}{\Delta g}\right)$	usually negative.

For each of the six situations (two types of cash flow for each case) an expression for ΔV can be found (see Appendix). In all

of these, ΔV is a function which depends on the size of the increment, Δ , AND on the value of one or more of the other factors in Equation (2). Table I shows which of the factors are involved. (The explicit relationships are given in the Appendix.)

TABLE I

Δ V Depends On

	Type 1 Cash Flow	Type 2 Cash Flow
Case I	Δ i, i, T, B	Δ i, i, T, g
Case II	Δ T, i, T, B	Δ T, i, T, g
Case III	Δ B, i, T	Δ g, i, T, g

The practical implications of this become apparent when some numerical results are worked out. Table II gives the values of V for various values of i, T, and B or g. Then some adjustments for uncertainty were applied. Table III gives the values of Δ V for these adjustments. Table IV measures the effect of the adjustment as a relative change, that is, $\Delta V/V \times 100\%$. (The values were chosen primarily to show the behavior of the system.)

TABLE II

Values of V

	i	B	g	T = 4	T = 8	T = 16
Type 1 Cash Flow	.1	-.05		2.997	4.552	5.756
	.2	-.05		2.515	3.409	3.760
	.2	-.10		2.276	2.828	2.73
	.4	-.10		1.704	1.880	1.878
	.4	-.20		1.413	1.362	1.260
Type 2 Cash Flow	.1		-.1	2.574	3.990	4.796
	.2		-.1	2.329	3.031	3.306
	.2		-.2	1.995	2.398	2.496
	.4		-.1	1.729	1.963	1.999
	.4		-.2	1.516	1.653	1.667

Note: A = 1 in all cases.

TABLE III

Δ V

Case	i	B	g	T=4	T=8	T=16
I-2	.1		-.1	.049	.117	.200
	.2		-.1		.075	
Δ i = .01	.2		-.2		.047	.060
	.4		-.2		.027	
Δ i = .02	.2		-.2		.100	.118
II-1	.1	-.05		.581	.294	.048
	.2	-.05			.140	
Δ T = -1	.2	-.10			.056	
	.4	-.10			.013	
	.4	-.20		.079	-.025	
II-2	.1		-.1	.496	.224	.045
	.2		-.1	.351	.106	.0096
Δ T = -1	.2		-.2	.249	.052	.0020
	.4		-.1	.189	.026	.00048
	.4		-.2	.124	.0113	.0001
Δ T = -2	.1		-.1	1.106	.499	.100
	.2		-.1	.96	.29	.026
III-1	.1			.061	.191	.475
Δ B = -.01	.2			.048	.119	.207
	.4			.030	.052	.062
III-2	.2		-.1	.05	.07	
Δ g = -.01	.2		-.2	.02	.08	
	.4		-.1	.023	.035	
	.2		-.1	.07	.15	
Δ g = -.02	.2		-.2	.05	.05	
	.4		-.1	.05	.14	

Note: A = 1 in all cases.

TABLE IV

Per Cent Change in V
($\Delta V / V \times 100\%$)

Case	i	B	g	T=4	T=8	T=16
I-2	(.1		-.1	1.9	2.4	4.2
	(.2		-.1		2.5	
$\Delta i = .01$	(.2		-.2		2.0	2.4
	(.4		-.2		1.6	
$\Delta i = .02$	.2		-.2		4.2	4.7
II-1	(.1	-.05		19.4	6.5	0.8
	(.2	-.05			4.1	
$\Delta T = -1$	(.2	-.10			2.0	
	(.4	-.10			0.7	
	(.4	-.20		5.6	-1.8	
II-2	(.1		-.1	19.3	5.6	0.9
	(.2		-.1	15.1	3.5	0.3
$\Delta T = -1$	(.2		-.2	12.5	2.2	0.1
	(.4		-.1	10.9	1.3	0.0
	(.4		-.2	8.2	0.7	0.0
$\Delta T = -2$	(.1		-.1	43.0	12.5	2.1
	(.2		-.1	41.2	10.4	0.8
III-1	The change is independent of the value of B.					
III-2	(.2		-.1	2.1	2.3	
$\Delta g = -.01$	(.2		-.2	1.0	0.3	
	(.4		-.1	1.3	1.8	
$\Delta g = -.02$	(.2		-.1	3.0	5.0	
	(.2		-.2	2.5	2.1	
	(.4		-.1	3.5	7.1	

Some interesting conclusions about the effectiveness of the adjustments may be drawn from the data in these tables:

1. When allowance for uncertainty is made by increasing the interest rate the effect on V depends on the expected life of the project, and is sensitive to the interest rate to which the adjustment is applied. This sensitivity in turn depends on the project life and on the rate of change of cash flow. To illustrate, consider the data for Case I-2 in Tables III and IV. If the project being considered has an uncertain interest rate, then that is the appropriate place to apply the adjustment. An adjustment of .01 (1%) might be considered adequate. Now if the interest rate is .1, this represents an adjustment of 10% in the rate. For a 4-year project whose cash flow is dropping off at a rate of 10% per year, the change in the value of the project is less than 2%. For a 16-year project the change is only 4.2%, and for an 8-year project it is 2.4%. Now if the interest rate is taken as .2, and all the other factors are held the same, then for an 8-year project the change is 2.5%, which is not appreciably different from the first situation where the effect was 2.4%. Of course, the absolute change has gone from .117 to .075, but then the value of V has also dropped.

Suppose the interest level is held constant, and the rate of change of cash flow, g, is varied. If g is increased from -.1 to -.2, the relative change in an 8-year project is from 2.5% to 2.0%. Now even though the relative change was only 2.5% to start with, the new value of g has caused it to decline by some 20% of itself.

By making similar comparisons in the other parts of Tables III and IV, these additional conclusions may be deduced:

2. When the life estimate is shortened, the relative effect very logically depends on the starting estimate. In addition, the relative effect is sensitive to the interest rate, i, and to the rate of change of cash flow, B or g. The degree of sensitivity to shifts in the levels of each of these two factors is influenced by the level of the other factor. (See Cases II-1 and II-2 in the Tables.)

3. The relative effect of adjusting the rate of change of net cash flow, g, depends on the level of g, on the life of the project, and on the interest rate. Again, the sensitivity to changes in these factors interacts with the other factors.

4. The effect of changing the rate of cash flow, B, does not depend on the level of B, but it does depend on the interest rate, i, and on the project life, T, and these factors also interact.

If all of this seems confusing, it is hardly surprising. Predicting the results of uncertainty adjustments of this sort is virtually impossible without lengthy calculations, although the general nature of the results should be intuitively evident in the formulas (see Appendix).

There are two general patterns which are not confusing and which are important:

1. Except for Δ B, a change in the size of the adjustment does not in general produce a proportionate change either in Δ V or in Δ V/V.
2. In all cases, the relative change in the present value,

V, is less than the relative change in the factor being adjusted, and the change is not steady or predictable in terms of magnitude. This is strikingly evident in the situation where $\Delta T = 2$, which for $T = 4$, 8, and 16 is a relative change of 50%, 25%, and 12.5%. Yet the relative change in the present value for this adjustment (for $i = .2$ and $g = .1$) for these T's is, respectively, 41%, 10%, and 1%!

CONCLUSION

If consistency is set as a rather modest and not unreasonable criterion for a satisfactory method of allowing for uncertainty, the methods discussed here must surely fail. Another criterion much used in the business world is simplicity. These adjustments are easy to apply; but if the notion of simplicity also includes ease of determining the effect of the correction, then these are not simple methods from the manager's point of view. The formulas are involved and they have too many variables to be readily tabulated.

The question of the impact of the uncertainty needs to be considered. It appears from the data of Tables III and IV that a moderate degree of uncertainty (up to say 10% of the estimated rate) in the interest (i) or in the rate of change of net cash flow (B or g) does not introduce crucial errors for short-lived projects. Further, the error seems to grow fairly slowly as the life of the project increases. It is doubtful whether the "present state of the art" of capital management in other respects

justifies making this the first area of research.

Uncertainty with respect to the life expectancy of the project is a different matter. If the life is long, an error of a few years one way or the other makes little difference (note the data in the column T=16 in Tables III and IV). For short-lived projects, the precision of the life estimate becomes crucial. Furthermore, the impact of the uncertainty is greatest at low rates of return. The implication is obvious: It is in the marginal projects that the dangers are greatest, and it is with these marginal projects that competitive struggles are resolved.

Since it is highly doubtful that anyone using rate of return procedures would anticipate the quantitative effects of the rule-of-thumb adjustments for uncertainty, the soundest advice would seem to be: Make your best estimates for the various factors which enter into the problem, then put them into the formula unaltered. An adequate method for treating uncertainty has yet to be developed.

APPENDIX on page 12.

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APPENDIX

The appropriate formulas for finding V and Δ V are:

For V:

Type 1 cash flow:

$$V = \int_0^T (A + Bt)e^{-it}dt$$

$$= \frac{A}{i}(1 - e^{-iT}) + \frac{B}{i^2}\left[1 - e^{-iT}(1 + iT)\right]$$

Type 2 cash flow:

$$V = \int_0^T Ae^{gt}e^{-it}dt$$

$$= \frac{A}{i-g}(1-e^{-T(i-g)})$$

For Δ V:

Case I-1: $$\Delta V = A\left(\frac{1}{i} + \frac{1}{i+\Delta i}\right) - (A + BT)e^{-iT}\left(\frac{1}{i} - \frac{1}{i+\Delta i}e^{-T\Delta i}\right) + B\left[\frac{1}{i^2} - \frac{1}{(i+\Delta i)^2} - e^{-iT}\left(\frac{1}{i^2} - \frac{1}{(i+\Delta i)^2}e^{-T\Delta i}\right)\right]$$

Case I-2: $$\Delta V = A\left[\frac{1}{i-g} - \frac{1}{i+\Delta i-g} - e^{-T(i-g)}\left(\frac{1}{i-g} - \frac{1}{i+\Delta i-g}e^{-T\Delta i}\right)\right]$$

Case II-1: $$\Delta V = \frac{1}{i}e^{-iT}(e^{-i\Delta T} - 1)(A + \frac{B}{i}) + \frac{BT}{i}e^{-iT}\left[(1 - \frac{\Delta T}{T})e^{i\Delta T} - 1\right]$$

Case II-2: $$\Delta V = \frac{A}{i-g}e^{-T(i-g)}(e^{\Delta T(i-g)} - 1)$$

Case III-1: $$\Delta V = \frac{\Delta B}{i^2}\left[1 - e^{-it}(1 + iT)\right]$$

Case III-2: $$\Delta V = \frac{A}{i-g}(1-e^{-T(i-g)}) - \frac{A}{i-g-\Delta g}(1 - e^{-T(i-g-\Delta g)})$$

ESTIMATING AND POST-AUDITING DIRECT LABOR SAVINGS IN A JOB-SHOP OPERATION

By

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ABSTRACT OF PART I*

Prepared by the Editorial Staff
of
The Engineering Economist

The management of the Ingersoll Milling Machine Company of Rockford, Illinois considers the saving in direct labor made possible by new equipment to be of utmost importance in any comparison of equipment investment alternatives. Because of the diversified nature of the products, no one machine can be associated with one product. Hence total time savings can be determined only on the basis of savings obtained from the production of typical parts which are representative of those produced in the past and are expected to be produced in the future. The time required to process each of the typical parts (six in the case of a 1942 Heald #74 Internal Grinder replaced in 1954) is generally obtained from stop-watch time studies or occasionally from historical records. Selected manufacturers of suitable equipment are asked to furnish operating times for the typical parts and are required by Ingersoll to guarantee the time performances.

Of the two suppliers approached for a replacement for the Heald Grinder, the Alpha Grinder Company decided not to quote on a

* The complete paper appeared in the Fall 1957 issue of The Engineering Economist.
Part II follows on page 15.

replacement because its equipment could not fulfill specifications. The Beta Grinder Company submitted a firm proposal for a machine to perform the required operations on all six typical parts, with estimates for operation times on the six parts. Calculations were then made of a weighted average of the expected saving, reflecting the estimated percentage of the total machine time spent on each of the typical parts. The expected annual saving in hours was obtained by applying the average percentage saving to the hours the old machine was in operation in the previous year. From this figure the direct labor saving in dollars was calculated by multiplying the hourly labor rate by the expected annual saving in hours. This was an estimated $4,100 of direct labor saving for the first year for the Beta Grinder, including additional work that would be transferred to the new machine.

EDITORIAL NOTE

The author of "Estimating and Post-Auditing Direct Labor Savings in a Job-Shop Operation" bases the contents of this paper on the results of his research under the terms of an Ingersoll Fellowship awarded by the National Center of Education and Research in Dynamic Equipment Policy at Illinois Institute of Technology. We regret that this information was inadvertently omitted when Part I was published in the Fall issue.

It will be noticed in Part II, following, that the Post-Audit is possible in the same terms of the replacement study, direct labor savings, because the replacement study specifically took into consideration that a post-audit would be made. The post-audit, therefore, was not independent, but rather was an integral part of the complete analysis.

Because of the importance of industrial post-auditing procedures and the general lack of published information concerning them, comments on this procedure, and additional material on other industrial procedures, will be welcomed by "The Engineering Economist" from its readers.

The Editor

PART II

The first part of this paper was concerned with the difficulties experienced by companies, engaged in a job-shop type of operation, in estimating probable savings in direct labor to be realized by procuring new production facilities. In addition to these difficulties, these companies encounter unique obstacles in any attempt to check whether these savings are being realized.

The purpose of the second part of this paper is to continue with a description of the practices followed by The Ingersoll Milling Machine Company. The particular procedure to be presented is the one related to the firm's post-audit phase of its equipment policy. It is believed that this description may suggest an approach which also can be adopted by others with little, if any, modification.

POST-AUDIT OF EXPECTED DIRECT LABOR SAVINGS

It will be recalled that the method employed by Ingersoll for computing direct labor savings calls for 1) selecting typical parts, 2) determining the time required to perform the operation on the old machine, 3) obtaining guaranteed production times for processing the parts on the new machine, 4) computing the per cent reduction in required production times, 5) applying this per cent to the total hours the old machine was in operation during the preceding year to arrive at the total hours of direct labor saved per year, and 6) multiplying this total by appropriate hourly rates to calculate the annual dollar saving in direct labor. Therefore, two things remain to be done at the time the

new machine is received and installed in the plant. First, it must be proved that guaranteed production times can be met. Second, it must be demonstrated that the machine is capable of reducing overall direct labor costs by the stipulated amount. The manner in which guaranteed production times are checked is the subject of this section. A discussion of the second activity will then follow.

PROVING GUARANTEED PRODUCTION TIMES

The activity of proving that guaranteed production times on typical parts can be met is under the control of the Methods department. As soon as possible after the delivery of the new machine, stop-watch time studies are taken of the operation on the parts on which time guarantees have been received. The point at which this can be done depends on the time required to install the machine, eliminate any operational difficulties which may be encountered, and acquaint the operator with the operating characteristics of the machine. In addition, some time may elapse before the respective typical parts appear in the production schedule. However, if the latter time becomes excessive, the methods analyst takes steps to schedule the production of these parts even if they are not required for current orders; in those cases, the completed parts are kept in stock.

Exactly the same techniques are employed in taking these studies as were used in studying the operation being performed on the old machine. Only productive elements of work are considered when computing the time required to perform the operation. The operator is instructed to work at a normal pace, and no

attempt is made by the analyst to rate the operator with regard to his efficiency. Instead, the foreman and methods analyst decide whether the man's performance is satisfactory. If it is, the assumption is made that the elapsed time is normal after having been reduced to compensate for all avoidable delays. In certain cases, a further adjustment of elapsed times is required to reflect the exact nature of the guarantee. For example, production times as supplied by the manufacturer of the replacement for the Heald grinder did not include set-up time. Consequently, the methods analyst, when studying the operation of this machine, would also reduce the total time by the set-up time to arrive at the time required to perform those elements of work included in the guarantee.

Upon the completion of a series of studies such as this on the new equipment, the methods analyst will find that guaranteed production times on each of the typical parts have or have not been attained. If they have, the manufacturer is notified accordingly and is thus absolved of all further responsibility. However, a problem arises when one or more of the guaranteed times cannot be met. In these situations, the methods analyst will first attempt to determine what the cause of the failure may be. For example, material hardness, finish required, or stock removed may differ from that specified when requesting time estimates from the manufacturer; the operator may not have had sufficient experience on the new equipment and may still be undergoing a learning process; or lot sizes may be appreciably smaller than those quoted on by the manufacturer, and the operator may not have enough parts to

permit his reaching an assumed level of efficiency. All such factors are considered with a view toward determining whether they are under the control of the Ingersoll shop. If they are, corrective action is inaugurated, and the studies are repeated. But once the methods analyst satisfies himself that all the conditions set forth in the guarantee are met and that stipulated production times still cannot be realized, the manufacturer of the equipment is apprised of the situation.

Notification of the manufacturer is always accompanied by a request that the builder send a representative to the Ingersoll plant to study the problem and demonstrate that the machine is capable of the performance promised. Upon his arrival, the representative cooperates with the machine operator, foreman, and methods analyst in an effort to solve the problem. It may be found that the solution lies in instructing the operator regarding the manner in which the equipment should be operated or in making certain methods improvements. If either the representative or the machine operator can perform the operation in the given time after these changes have been made, the manufacturer's responsibility is fulfilled. In some cases, however, the representative finds that time guarantees cannot be satisfied because of the machine's inherent design and construction. This was true in the case of the replacement machine for the Heald grinder. The Ingersoll operator was unable to perform the operations on any of the typical parts in the time estimated by Beta. The methods analyst found that the difficulty was not being caused by any conditions controllable by Ingersoll. The Beta company was notified accordingly. A service man was sent to

Rockford to study the problem. He found that, although the machine was being operated properly and the most efficient methods were being used, neither he nor the Ingersoll operator could produce the work in the guaranteed time. All indications were that changes in machine design were required. As is usual in situations such as this, Ingersoll personnel cooperated with the Beta representative to determine what changes should be made. It was finally decided that, first, putting a screw and a bracket on the head would make taper settings easier. Second, the general performance of the machine would be improved by installing a new guard for the front chuck of the machine and changing the position of the electric button control system. These changes were made by the builder, and their salutary effect was sufficient to permit realization of estimated production times on typical parts. Ingersoll notified the manufacturer that the guarantee had been satisfied.

Completion of this explanation of the manner in which the company determines whether manufacturers' guarantees have been satisfied provides an appropriate point at which to present a suggested criticism, of which Ingersoll management is aware, of the technique of using guaranteed production times as the basis of justification studies. The criticism is centered about the absence of estimating the machine operator's efficiency when checking production times for typical parts on the old machine and on its replacement. It has been suggested that the firm's current practice does not permit a realistic evaluation of machine performance and can lead management to make erroneous decisions with regard to equipment acquisition. The argument can be best presented by means

of a hypothetical case.

Let us assume, for the sake of simplicity, that only one typical part has been selected to represent the nature of the work going through an old machine. A time study of the operation in the shop indicates that the operator requires 120 minutes to complete the operation. However, 20 minutes of this total was time attributable to avoidable delays, and the methods analyst decides that 100 minutes represents the productive time required to complete the process on the machine.[1] Contact is made with a machine tool manufacturer who studies the work and submits a guaranteed time of 75 minutes. This represents a saving of 25 per cent over the old time which in this case was sufficient to approve the purchase of the replacement machine.

Let us assume further that after the machine has been delivered, time studies made by the Methods department show that operating time per unit on the new machine continues to be 100 minutes. The manufacturer is told that Ingersoll is unable to attain the guaranteed time and, unless the manufacturer's representative is able to demonstrate that the promised time can be realized, appropriate action will have to be taken. The manufacturer's operator arrives and performs the operation in 75 minutes, thereby absolving the supplier of any further responsibility.

The question which arises immediately is whether this demonstration proves that the new machine is 25 per cent faster

[1] The same thing could have taken place using historical work card data rather than stop-watch studies.

than the old one. The answer may be "No", for it is entirely possible that the manufacturer's operator was operating at a level of efficiency which exceeded that of the company's operator by an amount such that any increase in output must be attributed to an increase in operator efficiency rather than to an increase in machine efficiency. Even in cases in which the company's operator succeeds in demonstrating that the guaranteed time can be met, there is no assurance that the individual was working at the same level of efficiency when being timed on the old machine as he was when being timed on its replacement.

The argument concludes with the observation that in this case, which admittedly is an extreme one, management may very well have based its decision to make the capital investment on the erroneous assumption that the new machine was capable of increasing output per man-hour. Also, although in the illustration the emphasis was placed on a set of conditions in which the old machine was capable of producing at a higher level than was indicated, there is no reason for assuming that the opposite of this would never be true. In some instances, it is possible that favorable performance will be obtained from an old machine because of extraordinary effort on the part of the operator while being time-studied.[1] The danger here would be that the machine would be retained on the basis of this unusual performance whereas there may be a real need for replacement. Rating the operator's performance during the stop-

[1] This would not be true in those cases in which past work cards are used to obtain representative production times.

watch study would minimize the danger of both premature and delayed replacements. New equipment would be evaluated in light of its efficiency relative to the efficiency of the old equipment. Neither production facility would be credited or condemned for apparent differences in production potential because of unrecognized changes in direct labor efficiency.

Ingersoll management counters this argument with a number of observations. First, although not most important, factors other than direct labor are taken into consideration when deciding whether to retain or replace equipment. This will tend to reduce the number of cases in which a possibly incorrect estimate of direct labor savings would result in an erroneous decision. Second, the reliability of existing performance rating techniques is still questioned by many authorities. Regardless of how formalized the rating method used is, judgment plays an important role. Third, if judgment must be employed in even the most scientific rating methods, there is no reason to believe that these methods will provide results more accurate than those obtained from the procedure followed at Ingersoll. It will be recalled that the methods analyst and foreman review the results of each study to determine whether the resultant operating times are, in their judgment, normal. Finally, two points are made with respect to that phase of the argument devoted solely to the danger of exaggerating potential savings in direct labor. One, guaranteed production times obtained from suppliers of machine tools tend to be conservative. Because of the commitment implied in the guarantee, manufacturers attempt to reduce the risk they incur by sub-

mitting times which ordinarily exceed those they estimate to be realistic. This has been verified by Ingersoll in its post-audit studies. Therefore, if anything, computed direct labor savings are understated. A second point is that a check of the accuracy of the estimated savings in direct labor does not end with the realization of guaranteed times for typical parts. Satisfying the guarantee demonstrates only that the new machine is probably capable of making the expected saving. Whether it will do so remains to be proved in time by the Methods department. This proof takes the form of periodic performance reports on each machine installed in the shop.

THE MONTHLY PERFORMANCE REPORT

It was stated that following a demonstration that guaranteed production times can be met, management demands that the new machine be shown capable of reducing over-all direct labor costs by the amount stipulated in the justification study. The nature of the check, however, is such that no attempt is made to ascertain this saving in terms of dollars and cents. Instead, the procedure calls for the determination of the per cent reduction in direct labor time; this per cent is then compared to that which had been used by the Methods department when computing the dollar saving in direct labor. The reason for this is that, after having estimated the per cent reduction in time required to process typical parts, the methods analyst is instructed to assume, first, that the new machine will operate at a level represented by last year's output on the old machine and second that labor rates will

remain unchanged. It is the company's chief executive who evaluates any possible changes in the assumed rate of production and hourly labor rates. Therefore, to eliminate the effect of any changes in these two factors, the methods analyst concentrates solely on reductions in direct labor hours expressed as a per cent of the time that would have been required to perform the given amount of work on the old machine. The procedure in brief calls for the methods analyst to determine the amount of time required to perform the work going through the new machine during a certain period. This is compared to the amount of time that would have been required to process the same amount of work on the old machine. The resultant saving is then expressed in terms of a per cent and serves as the basis of a Performance Report on the new machine.

A Performance Report is prepared monthly for at least six months after a machine has been received, installed, and released for production in the Ingersoll shop. The minimum period of six months would apply in those cases in which a new machine demonstrates consistently for the full period that anticipated reductions in operating times are being realized. Where this is not true, longer periods are involved. For example, if during the first six months a new machine indicated satisfactory savings for only the last two of these months, the period might be extended for four or five months or until management is convinced that the machine has proved its ability to provide expected benefits. In isolated cases, checks of this type have been made for eighteen months on a particular machine.

The six-month period was selected by management as a compromise between the cost of preparing the report and the value of the information it makes available. It is realized that ideally studies of this type should be made throughout the life of the machine; however, the cost would be prohibitive. As a result, the assumption is made that a satisfactory performance for six months is sufficiently indicative of the fact that past estimates were accurate.

Results of the monthly survey are recorded by the Methods department on a form which has been designed for this purpose. A copy of this form is shown in Figure 5. It will be noted that the first four columns provide for recording the machine number, its description, the date on which it was received, and the shop department in which the equipment is located. The next column, Vendor's Promised Increase, refers to the estimated per cent saving in direct labor hours based on typical parts. The second section of the form provides space for recording the actual per cent saving realized per month during a six month period.

The first step in the calculation of this saving requires that the methods analyst determine what work was processed on the new machine during the month for which a report is being prepared and the time required to perform this work. When preparing the Performance Report for any one month, the methods analyst begins with that month's Report of Direct Labor Hours for Individual Parts for a given new machine. On a work sheet, he lists all the parts involved and the respective operating times. He then removes the file of reports accumulated for the old machine. This file is

NEW MACHINES PUT INTO PRODUCTION

Date: _____

MACHINE	DESCRIPTION	DATE REC'D.	DEPART-MENT	VENDOR'S PROMISED INCREASE	Percentage of Production Increase & Percentage of Total Machine Hours											
					Actual Increase	% of Hours Worked	Actual Increase	% of Hours Worked	Actual Increase	% of Hours Worked	Actual Increase	% of Hours Worked	Actual Increase	% of Hours Worked	Actual Increase	% of Hours Worked

Figure 5. Performance Report Form

available because, as mentioned, the Report of Direct Labor Hours for Individual Parts is also prepared for all machines being studied for replacement. The reason for doing so is to develop a summary record of past operating times on the old machine. Serious consideration is given to the replacement of a machine on the average of almost two years before the actual replacement is made. During this period, decisions are made with regard to possible suppliers, typical parts to be submitted for time estimates, and machine capacity required. In addition, required time studies are being taken, a justification study is being prepared, and time is spent working with representatives of various machine tool manufacturers. Finally, when the order is actually placed, a number of months elapse before the machine is delivered and installed. As a result, an ample opportunity exists for developing performance data on the old machine. Management gave consideration to the fact that this time period may not be sufficient to accumulate information on a satisfactory cross-section of the parts going through the machine. However, it was also realized that, if it were necessary to go back further than two years, the resultant information would probably be of little value since it would represent times during a period in which the machine might have been fairly efficient relative to its condition at the time of replacement.

Therefore, the Methods department has a complete record readily available of all the work processed on the old machine for a period of about two years preceding its replacement. Consequently, after listing the parts and operating times for a new machine

during a particular month, the analyst can review the Reports of Direct Labor Hours for the old machine and is able to determine past operating times for those parts which had been produced formerly in the required lot sizes. If more than one time is available for a given part, an average is taken.

This is then followed by a tabulation of all the parts which have been produced on the new machine and for which past operating times are available. The times required to process these parts on the old and new machines respectively are then listed and totalled. The difference is taken to arrive at the hours saved. This difference is divided by the total hours that would have been required to perform the work on the old machine to determine the saving in per cent. In addition to recording this percentage on the Performance Report form, the analyst calculates and records the per cent of the total hours the new machine was in operation for which he was able to obtain past operating times. Of course, a 100 per cent comparison will never be possible because of new work and the fact that some of the work had not been done on the old machine during the last two years of its life.

EVALUATING ACTUAL MACHINE PERFORMANCE

Some time ago, Ingersoll management asked itself whether the results of the post-audit procedure, as expressed in the Performance Report, really demonstrate that a new machine is performing satisfactorily or not. In other words, if the actual saving is calculated to be less than the expected saving, is the machine to blame? Or if the actual saving exceeds the expected saving, is the machine to be credited for this? These questions could be

answered only by analyzing the basis on which the expected saving in per cent is computed.

The per cent reduction in direct labor hours is determined from an estimate of the savings expected on typical parts. However, the lot size associated with each typical part is assumed to represent the lot size to be associated with every part falling into the category of work represented by that typical part; this is important because set-up time is independent of lot size. In addition, an estimate is made of the portion of the total production time that can be attributed to each of the categories of work; as a result, the average saving is a weighted average. The significance of these observations will be demonstrated by using data on the Heald grinder and its replacement. These data which have been presented at various points in this paper are summarized in Table 1.

A review of Table 1 reveals, first, that set-up time is added to grind and load time before the per cent saving is computed; no saving is expected on set-up. Second, savings on the typical parts range from 28 to 65 per cent. Therefore, the average saving of 56 per cent will be a valid standard by which machine performance can be evaluated only if 1) the actual proportion of time spent on each category of parts corresponds to the expected proportion of time and 2) actual lot sizes correspond to expected lot sizes. Any variation in the product mix and lot-size mix would necessitate a revision in the expected standard. The difficulties that arise can be seen in the following hypothetical cases.

For purposes of simplicity, let us assume that during a

Table 1. Summary of Time Data Related to the Heald Grinder and its Replacement

		Old Machine			New Machine					
Part Number	Lot Size	Set-Up Time (Min.)	Grind and Load Time (Min.)	Total Time (Min.)	Set-Up Time (Min.)	Grind and Load Time (Min.)	Total Time (Min.)	Time Saved (%)	Total Production Time (%)	Contribution To Average Time Saved (%)
11685-R	1	24	83	107	24	17	41	62	4	3
13901-R	10	36	480	516	36	200	236	54	19	10
15454-X	8	30	960	990	30	320	350	65	36	23
18803-X	2	42	408	450	42	218	260	42	16	7
52210-R	4	24	120	144	24	80	104	28	5	1
52211-R	4	24	528	552	24	184	208	62	20	12
Total									100	56

particular period the only parts produced on the new machine were three of the six typical parts. Also, each part was produced in the expected lot sizes in the time shown below:

Part Number	Lot Size	Total Production Time New Machine	Old Machine
13901-R	10	236 Min.	516 Min.
18803-R	2	260	450
52210-R	4	104	144
Total		600 Min.	1110 Min.

The usual post-audit procedure would indicate a time saving of 46 per cent. Measured against the standard of 56 per cent, the result might lead one to believe that machine performance is poor. And yet, comparing the actual production times with those shown in Table 1 as being estimated for each of these parts reveals that each of the parts was produced in the guaranteed time. The machine efficiency is being understated because the product mix during the period under consideration was such that the only parts produced were those for which expected savings were less than the average. Of course, at the other extreme, the parts produced might be those for which expected savings are higher than the average; current procedures would then overstate the equipment's performance.

A similar illustration could be developed to show the effect of variations in lot-size mix on the computed saving. It is conceivable that in any one period the product mix could coincide exactly with that assumed in the justification study. And yet, lot sizes could be much smaller than those estimated for each of the parts. As a result, set-up time per unit would be higher,

thereby increasing the total production time per unit. In addition, a larger portion of the total time would be spent on set-up for which no saving was expected. This would be no reflection on the machine's performance, but nevertheless the computed saving would be less than the established standard of 56 per cent even if the machine completed all the other elements of work in the guaranteed time. Conversely, under the same conditions, lot-sizes in excess of those on which the standard was based would suggest that the machine's efficiency was higher than expected. This conclusion would naturally be incorrect.

Therefore, if at the end of any one month the president is given a report to the effect that a machine with an expected time saving of 56 per cent yielded an actual saving of say 40 per cent, he has no way of knowing whether this is due to poor machine performance, an unfavorable product mix, an unfavorable lot-size mix, or some combination of the three. On the other hand, a saving in excess of the one expected could not be identified as reflecting good machine performance, a favorable product mix, or a favorable lot-size mix.

Having become aware of this problem, Ingersoll management investigated the possibility of developing a procedure to aid in the interpretation of computed savings. A description of what was decided upon follows.

One of the difficulties associated with the use of an average expected saving is created because the average saving does not coincide with the expected saving on each of the typical parts. To evaluate the performance of a new machine, it would be necessary

to obtain a print of each part which had been processed on both the old and new machines and for which elapsed operating times were available. The prints would be studied by the methods analyst to determine the category of parts into which each part should be placed. The per cent saving would then be computed for each category and compared to the expected saving for that category. With this approach, if a larger portion of the total time were spent on work for which savings were expected to be less than average, it could be pointed out that this was the reason for the actual average saving being lower than expected. A higher average saving than expected may be found to be attributable to the fact that most of the work was done on parts falling into a category for which a higher than average saving was to be expected.

This, however, would not solve the problem of variations in the lot-size mix. Since set-up time is independent of the lot size, it would be necessary to consider this activity as a separate category of work for which the expected saving, if any, would be stipulated. Preparation of a Performance Report would require calculating the actual per cent saving on set-up and the actual per cent saving on the machining operations for each of the categories of parts. The necessary analysis could then be made. But as would be expected, this would necessitate some changes in the manner of computing direct labor savings for justification purposes. The entire procedure can be illustrated as follows, using the old Heald grinder as an example.

From Table 1, it can be seen that six work load classes were selected. The per cent saving for each was determined on the basis of total operating time including set-up. Under the new

approach, set-up time would be handled as a separate work load class to permit evaluation of the effect of varying lot-size mixes. Time saved on each of the typical parts would be determined on the basis of grind and load time only. This would yield the following results:

Number	Grind and Load Time Old Machine	New Machine	Time Saved
Set-Up[1]	-	-	0%
11685-R	83 Min.	17 Min.	80
13901-R	480	200	58
15454-X	960	320	67
18803-X	408	218	47
52210-R	120	80	33
52211-R	528	184	65

Next, the portion of the total production time spent on each of the above classes of work would have to be estimated to arrive at the average per cent saving. However, it would be possible to place part numbers 15454-X and 52211-R in one class since their respective savings are almost equal. For purposes of illustration, let us assume that the proportion of total production time spent on each work load class is as shown below. The average expected saving is computed accordingly.

Part Number	Work Load Class	Per Cent of Total Production Time	Per Cent of Time Saved	Contribution to Average Per Cent Saving in Direct Labor
Set-Up	1	7	0	0
11685-R	2	3	80	2
13901-R	3	17	58	10
15454-X) 52211-R)	4	54	66	36
18803-X	5	15	47	7
52210-R	6	4	33	1
Average Saving				56

[1] It will be recalled that in this case, no saving was expected for set-up.

It is important to note that an average saving of 56 per cent can be realized only if 1) the operator works at an assumed level of efficiency, 2) the proportions of total time spent on the various work load classes coincide with those on which the standard of 56 per cent is based, and 3) the machine is as efficient as expected. Since management, for reasons already given, assumes that operator efficiency is satisfactory, only the last two items must be considered.

Under the existing procedure, the methods analyst would prepare a performance report on the new machine for a given month by comparing operating time on the new machine with a comparable figure for the old machine. For example, for the machine already referred to in this illustration, an end of month comparison may reveal the following hypothetical situation:

Part Number	Quantity Produced	Elapsed Production Time: Old Machine	Elapsed Production Time: New Machine
74882-R	1	2.5 hrs.	1.4 hrs.
119920-J	2	1.5	1.0
75778-R	10	12.9	6.6
20892-X	1	5.1	2.5
76976-R	1	2.7	1.2
		24.7 hrs.	12.7 hrs.

The average saving would be 49 per cent which when measured against the standard of 56 per cent would suggest that machine performance is unsatisfactory.

Under the proposed procedure, the analyst would first determine what portion of the production time for each part was set-up and what portion grind and load. Next, he would obtain part prints for each of the parts to determine the work load class into which

each falls. Let us assume that the result of this analysis is as follows:

Part Number	Work Load Class	Elapsed Time[1] Old Machine	Elapsed Time[1] New Machine
Set-Up	1	2.6 hrs.	2.4 hrs.
74882-R	6	2.1	1.0
119920-J	6	1.1.	0.6
75778-R	5	12.3	6.2
20892-X	5	4.4	1.8
76976-R	4	2.2	0.7
Total		24.7 hrs.	12.7 hrs.

This breakdown now permits the analyst to evaluate the actual saving of 49 per cent. The first step is to compute the saving realized in each work load class and determine the per cent of total operating time each work load class represents. This yields the following results:

Work Load Class	Elapsed Time on Old Machine	Per Cent of Total Time Actual	Per Cent of Total Time Expected	Elapsed Time on New Machine	Time Saved Actual	Time Saved Expected
1	2.6 hrs.	10%	7%	2.4 hrs.	8%	0%
2	0	0	3	0	0	80
3	0	0	17	0	0	58
4	2.2	9	54	0.7	68	66
5	16.7	68	15	8.0	52	47
6	3.2	13	4	1.6	50	33
Total	24.7 hrs.	100%	100%	12.7 hrs.	49%	56%

An analysis of these results reveals that: 1) actual savings for each of the classes of work produced is greater than expected but 2) actual time, spent on classes of work for which expected savings were less than average, exceeded the expected time. Conclusions to be drawn are first that, although the actual saving

[1] Elapsed time shown for part numbers represents total time less set-up.

is less than the expected saving, machine performance is satisfactory, and there is no need to look for deficiencies in the equipment. Second, estimates made by the Methods department with regard to the proportion of total time spent on each work load class are incorrect for this particular month. This type of interpretation would not have been possible with the existing procedure.

Although Ingersoll management recognizes the advantages of a thorough analysis such as this, it has concluded that the benefits would be offset by the cost of maintaining the procedure. To begin with, set-up is not shown on Daily Job Cards as a separate item. To do so would increase the time spent by machine operators in recording starting and completion times. In addition, clerical and administrative costs of processing these data in the Accounting and Methods departments would increase appreciably. Next, part classification by the methods analyst would require the reproduction of prints of all the parts being produced on machines whose performance is being studied. An average of about fifteen machines is being checked at any one time, and approximately ten different parts are produced on each machine daily. This means that about 150 prints would have to be reproduced each day. Not only is the cost of this reproduction prohibitive, but a great deal of time would be required to study each print to determine the work load class for each part. Also, personnel with the ability to perform this analysis are not available in sufficient numbers. As a result, a compromise solution has been decided upon.

When he receives the monthly Performance Report, the company's

president reviews the saving in direct labor for each machine. If the actual saving is satisfactory as measured against the expected saving, no further analysis is made. Performance is considered satisfactory regardless of the combination of factors to which this performance can be attributed; the important thing is that the expected saving is being realized. It is important to note that this is the case with almost every new machine procured. In the exceptional cases in which actual savings are less than those expected, the Methods department knows that it is its responsibility to discover the cause. The course of action taken varies in each particular case. If the deficiency in performance is relatively small, nothing will be done. For example, an actual saving of 55 per cent on a machine expected to save 56 per cent would not justify inauguration of a plan for corrective action. The same would be true for those cases in which the difference between expected and actual savings is appreciable for say one out of six months. However, if a unit of new equipment consistently fails to meet the standard by a significant amount, a detailed investigation is made of the problem.

The nature of the investigation is influenced to some degree by whether guaranteed production times on typical parts have been met either by the Ingersoll operator or the manufacturer's representative. If not, the Methods department studies the machine with a view toward making certain changes in its design. But if production guarantees have been met and a study reveals that the machine's operating characteristics cannot be improved upon, the methods analyst will give consideration to the fact that estimates

on which the justification study was based might be incorrect. In these cases, which are rare, a detailed analysis is made of the work going through the machine in accordance with the procedure outlined in this section. Part prints are obtained and categorized by work load class. Lot sizes are reviewed and set-up times estimated. In this manner, the analyst is able to determine whether assumed lot-size and product mixes are realistic. A review of the company's records reveals that, in those isolated cases in which expected savings were not being realized, the problem was always to be found in the equipment's design, which could be corrected, or in erroneous estimates of the nature of future production. But even in the latter instances, the discrepancies were never serious.

It will be recalled that difficulties were encountered in attaining guaranteed production times on the replacement for the Heald grinder. During this initial period, performance reports were also being prepared, and as would be expected, average savings were not satisfactory. This continued for the few months required by the manufacturer to make the necessary improvements on the equipment. After these had been made, guaranteed times were attained, but although average savings increased, they did not reach a satisfactory level. A comprehensive survey was made of the parts being processed on the machine, and it was found that a large majority of them fell into a work load class for which the expected saving was less than the expected average saving.

Nevertheless, there was reason to believe that this was a temporary condition. Time was to prove that this belief was

correct. Performance Reports were continued far beyond the minimum six-month period, and eventually actual savings reached the predicted level.

FURTHER OBSERVATIONS

This concludes the description of the manner in which one firm checks the accuracy of its estimate of the saving in direct labor to be realized from the replacement of an existing production facility. It was seen that the approach, in spite of certain compromises made to reduce the cost of obtaining the required information, is relatively complex. But Ingersoll management realizes that the nature of its operations precludes the development of a simple procedure. On the other hand, it is aware of the fact that any post-audit study, even though imperfect, provides valuable information. First, it may reveal a tendency to overestimate or underestimate savings in direct labor to be realized from the acquisition of new equipment; if so, steps can be taken to eliminate this bias when making subsequent studies. And second, such studies may show that action must be taken in any one case to eliminate conditions which serve as obstacles to the realization of anticipated benefits; if this is true, appropriate corrective measures can be inaugurated.

In summary, therefore, an attempt has been made to show that companies engaged in intermittent manufacturing can develop procedures which will contribute toward the making of sound estimates of direct labor savings for use in equipment replacement analyses and to show further that an approach can be developed for determining whether these savings are being realized. Naturally, the

methods employed will not be as straightforward as those that can be used by the company whose production equipment is procured for the purpose of performing a stipulated operation on large quantities of a single product. There is no doubt that the job-shop type of operation does present unique problems, but these problems do lend themselves to solution. The manner in which one company has solved them can serve as a guide to organizations operating under similar conditions.

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SIXTY-SIXTH ANNUAL MEETING

AMERICAN SOCIETY FOR ENGINEERING EDUCATION

The American Society for Engineering Education will hold its Sixty-Sixth National Meeting at Berkeley, California June 16th-20th, 1958.

The program of the Engineering Economy Division has been tentatively planned to include afternoon conferences on Monday and Thursday, a joint luncheon on Wednesday, and a Wednesday evening dinner; and to cover the topics of (1) capital budgeting, (2) the economic consequences of unreliable complex equipment, (3) highway cost allocation, and (4) sunk costs and their implications for managerial decisions.

A roster of outstanding speakers is nearing completion, and an announcement of final arrangements will appear in this journal.

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SYMPOSIUM ON THEORY OF DECISION PROCESSES

"Theory of Decision Processes" is the title of a two-day symposium to be held on May 8-9th, 1958 at Purdue University. Topics to be covered include inventory theory, stochastic theory of decisions, information and optimality criteria in decision theory, multistage linear programming, dynamic programming.

This conference is sponsored by the Industrial Engineering Department in cooperation with the Department of Mathematics and Statistics and the Department of Industrial Management of Purdue.

For further information, write to T. E. Bartlett, 114 Heavilon Hall, Purdue University, West Lafayette, Indiana.

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Review

THE ECONOMIC DESIGN OF $\bar{X}$ CHARTS USED TO MAINTAIN CURRENT CONTROL OF A PROCESS: MODEL I*

In this report Duncan is concerned with the Shewhart $\bar{X}$ chart as a device for maintaining control over a process, and in particular with replacing the old rule-of-thumb ("Use three sigma limits and a sample size of four or five.") by a somewhat more rational method for assigning values to the $\bar{X}$ chart design variables. The model explicitly includes economic factors and treats mostly of the significant design variables; but these advantages are obtained only at the expense of rather severely restricting the type of situation to which the results may be applied. These limitations, and Duncan's general approach to the problem, may perhaps be best described in terms of the three "pre-design" decisions which must be made before the design of any particular type of control device can be undertaken:

1. Choice of which design factors are to be parameters (with values assigned in advance), and which are to be variables (with values to be fixed in the course of design);

2. A precise characterization of the process to be controlled; and

3. An explicit choice of the criterion by which the control device is to be evaluated.

The design variables in the proposed model are sample size, placement of control limits, and the frequency of sampling; it is the purpose of the analysis to determine the "optimal" values for these variables. The rule for taking action to correct a change

* ACHESON J. DUNCAN: "Technical Report No. 24", Applied Mathematics and Statistics Laboratory, Stanford University. (This report also appeared in the Journal of the American Statistical Association, Vol. 51, No. 274, June 1956, pp. 228-242.)

in the process is the principal design parameter which has been assumed. In the author's words, "We shall restrict ourselves here to the simple rule of taking action only when a [single] point exceeds the control limits . . . The question of what is an optimal rule is beyond the scope of this paper." Since the principal design factors are considered as variables, the limitation of consideration to the stated simple action rule does not bulk as an undue restriction. However, it is quite a different matter when we turn to the characterization of the process.

The process is assumed to be acted on by a single assignable cause[1] which (when it occurs) produces a known and constant shift in the process mean; the process variance is presumed constant throughout. The occurrence of the assignable cause is assumed to be random (in the sense that arrivals of "customers" are random in the simpler queuing models). The only other assumption about the process is that "In the particular model discussed in this paper (which we have chosen to call Model I) the process is allowed to continue in operation during the search for the assignable cause." Making use of this particular characterization of the process to be controlled, and making some apparently justified approximations, the author is able to derive a number of useful measures of process behavior, e.g., mean time for the occurrence of the assignable cause, mean time to catch the resulting shift in the process mean, average time the process will be out of control, etc.

[1] Section 4 of the report gives a brief discussion of the problem of multiple assignable causes, but no results of practical utility are presented.

The applicability of the model is limited to processes acted on by a single randomly occurring assignable cause producing a known and constant shift in the mean. It is not the reviewer's intention either to quarrel with Duncan's assumptions or to question the necessity of making them or others equally limiting. The fact remains, however, that the result is a rather severe restriction on the practical applicability of the ensuing analysis.

The criterion measure employed in this paper is, in essence, expected hourly cost, and includes the following factors: expected cost (or lost income) when the process is operating out of control, i.e., when the mean has shifted; expected cost of "false alarms", i.e., of looking for a shift in the process mean when no such shift has actually occurred; costs of sampling, inspection, and charting which are independent of sample size; and costs of sampling, inspection, and charting which are directly proportional to the sample size. Specifically excluded from the criterion function are the costs of process adjustment and/or repair, including possible process shutdowns, and the cost of bringing the process back to a state of control subsequent to the discovery of the assignable cause.

Although rather complex in form, the criterion function seems to include the major types of costs incurred in using an $\bar{X}$ chart for process control. The complexity of the expression is underscored, however, when it is differentiated to establish the conditions for minimum cost: the resulting equations are completely unmanageable. By a skillful restriction of the ranges of certain parameters, the author is able to replace the exact equations by

considerably simpler approximations. With the aid of a chart included in the report, one may then find the (approximate) optimal values for sample size, control limits, and frequency of inspection. (The procedure is iterative, but apparently converges quite rapidly, requiring only two or three steps to obtain an answer of satisfactory accuracy.)

Numerical examples are presented which show that in eleven out of twelve cases the approximate optimal values yielded a total cost within six per cent of the true minimum as determined by trial and error. Comparison with a conventional "three sigma limit - sample size of five - one hour sampling interval" $\bar{X}$ chart reveals that substantial savings may be realized in some practical situations by employing the optimal values for the control chart design variables. Drawing on the results of the numerical examples, Duncan presents some interesting and useful conclusions concerning the effects of various factors on the optimal values of the design variables.

Despite the limitations imposed by the various assumptions made, this report provides what is perhaps the best currently available guide to the economic design of $\bar{X}$ charts. The author states that other models are under investigation. It is to be hoped that the publication of the results of these studies will further extend the usefulness of the results of the present report.

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Review Article

COST CONCEPTS FOR BUSINESS MANAGEMENT *

By

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For years managers have been emphasizing the need for better cost information upon which to base their decisions, since the preparation of accounting reports on income and financial position of itself does not provide adequate information for use in the managerial functions of planning and control.

For those managers who have been fearful that the accounting profession appeared to be orbiting around the preparation of reports on financial position and income there is new hope, for a recent series of three articles in The Accounting Review indicates that the pleas for better cost information that have been voiced from without the accounting profession are now being echoed from within. The three articles mentioned were written by members of the Cost Committee of the American Accounting Association.

In 1936 the Executive Committee of the American Accounting Association issued a tentative statement on the preparation of a financial position and income reports. The Cost Committee has

* Literature cited:

ANTHONY, ROBERT N.: "Cost Concepts for Control", The Accounting Review, Volume XXXII, Number 2, pp. 229-234, April 1957.
BEDFORD, NORTON W.: "The Nature of Business Costs, General Concepts", The Accounting Review, Volume XXXII, Number 1, pp. 8-14, January 1957.
THE COMMITTEE OF COST CONCEPTS AND STANDARDS: "Tentative Statement of Cost Concepts Underlying Reports for Management Purposes", The Accounting Review, Volume XXXI, Number 2, pp. 182-195, April 1956.

expressed hope that its report on cost concepts will result in improved cost accounting activity comparable to the benefits attributed to the 1936 report on basic concepts for financial and income report preparation. Specifically, the avowed objectives of the Committee are:

(1) To stimulate further study and discussion of the accounting information needed by management.

(2) To suggest cost data which are pertinent to various types of management problems.

(3) To call attention to the broad and indefinite nature of cost as a general term and to reveal how appropriate costs depend upon the purpose for which they are to be used.

(4) To describe a portion of the field of accounting within a framework sufficiently broad to provide an insight into the problem of providing accounting information for management purposes.

The Committee further points out that "the development of techniques and procedures to provide the most reliable approximations of the basic costs is beyond the scope of this statement. Such procedures and techniques may be expected to differ from enterprise to enterprise but the basic concepts of cost set forth here are the underlying concepts toward the realization of which the specific techniques and procedures strive. The basic concepts are believed to have rather general application."

In an effort to provide a definition of cost which will enjoy widespread acceptance and which will provide a foundation for a framework of cost concepts, the Committee has presented the following definition: "For business purposes, cost is a general term for a measure of value purposefully released or to be released in the acquisition or creation of economic resources, either

tangible or intangible." The Committee then goes on to discuss cost concepts as applied to resources to be acquired and fully consumed, resources to be acquired and partially consumed, resources on hand and fully consumed, and resources on hand and partially consumed.

In discussing cost reports for control purposes, the Committee points out that " . . . control can be achieved only before the fact. Nothing that happens after the fact can in any way alter or undo what has already been done." Perhaps this statement will be more widely proclaimed by managers than any other statement made by the Committee. In fact, many management personnel probably will claim to have made such a statement themselves almost daily for years, and will add that it is about time that the accounting profession should see the light! Actually, such an attitude by individual managers may be quite justified in view of the number of accountants who seem to feel that accounting reports are an end of themselves rather than a means to the end of improved managerial action.

Of considerable significance to the practitioner is the fact that the reports represent only an outline, or framework, of the desired measures of cost which should be provided. Although it is hoped that the Committee's work will lead to the eventual improvement of techniques and procedures for the determination of costs, anyone seeking such improved techniques and procedures will not find them in the papers mentioned. In fact, while reading the papers by the Committee and its individual members one can't help but feel that most of the basic problems of cost determination are

being sidestepped because the current level of accounting technology does not provide the means for solving these problems. One may even get the feeling that perhaps the Committee has been a little too eager to develop a widely accepted framework of cost concepts. Perhaps there should have been less emphasis on such things as the development of definitions which had to be rather vague in order to be widely accepted and more emphasis on the possibilities for developing tools and techniques for the analysis of costs and their variations.

Although the Committee's work will serve to point the way, tangible progress in the development of better cost data must await the development of new and improved analytic tools and techniques. It is the author's hope that with accountants as well as line managers concerning themselves with the problem, the above-mentioned tangible progress will be recognizable in the not-too-distant future!

Of the three reports, the one entitled "Tentative Statement of Cost Concepts Underlying Reports for Management Purposes" is the most comprehensive. The other two reports can be considered only as supplemental since they serve only to reiterate (along with some elaboration on) the material found in the first report.

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Review

CAPITAL BUDGETING and THE PROBLEM OF REINVESTING CASH PROCEEDS*

There have been a number of articles in the literature during the past ten years supporting the internal rate of return approach to capital budgeting problems. In addition, a number of articles have been written to illustrate cost and revenue patterns that are misleading when making internal rate of return calculations. Harold Bierman and Seymore Smidt have summarized a portion of this material in their recent article on "Capital Budgeting and the Problem of Reinvesting Cash Proceeds".

The definition for the internal rate of return of an investment used by Bierman and Smidt is: "The rate of discount that equates the present value of the cash expenditures required by the investment with the present value of its cash proceeds." This, in essence, yields a rate of interest which a program or project will "pay" along with replacement of principal to the firm.

Early in their article Bierman and Smidt mention cut-off rates. The cut-off rate separates programs with an acceptable rate of return from those of lower rate of return. While it is true that no general agreement exists on how to determine cut-off rates, there are general distinctions to be drawn. Lorie and Savage[1] point out

* HAROLD BIERMAN and SEYMORE SMIDT: Journal of Business, Vol. XXX, No. 4, pp. 276-279, October 1957.

[1] JAMES H. LORIE and LEONARD J. SAVAGE: "Three Problems in Rationing Capital", Journal of Business, XXVIII, No. 4, pp. 229-239, October 1955.

that some managements just don't like to borrow money or issue new securities; they find it more comfortable to plow back some earnings and grow on these. In these cases the cut-off rate is determined through allocation of funds available to the highest rate of return projects available. An alternative cut-off rate is the "cost of capital". This is the rate at which funds (or an increment of funds) may be obtained (borrowing, sale of stock, etc.). This approach assumes that we will undertake every project that will repay the firm at a rate higher than the rate the firm must pay for an increment of capital equal to the projects' cost. B and S accept the "cost of capital" as their cut-off rate. Within the framework of a theoretical discussion this appears acceptable.

Both the recent article by Bierman and Smidt and an earlier article by Ezra Solomon[1] point out one case where two or more investments indicate the need for further calculation than their own internal rate of return. This situation arises when the reinvestment of cash proceeds (at cost of capital rates) from the shorter of two programs, with a higher rate of return over its own project life, does not yield an over-all return equal or greater than a lower rate of return program when both or all projects are projected over the longer (longest) project's life. Bierman and Smidt discuss this problem as applying to all programs being compared in a "fixed sum of money for investment" situation. They

[1] EZRA SOLOMON: "The Arithmetic of Capital-Budgeting Decisions", Journal of Business, Vol. XXIX, No. 2, pp. 124-129, April 1956.

infer that Solomon recognized the problem solely for "mutually exclusive" programs (should we build a bridge or build a ferry - clearly not both). While it may be incorrect to make this inference, Bierman and Smidt are right in pointing out the need for recognizing this problem in its broadest aspects. Two related comments may be made on the "mutually exclusive" investments situation. First of all, we are excluding either the bridge or the ferry because of a characteristic, not a low rate of return. One or the other, or both, should be excluded on the basis of rate of return and the sum of capital available. Second, we have four choices, the bridge, the ferry, neither, or both. A proper rate of return analysis would include the case of both and eliminate this possibility only when it was excluded by cut-off rate or sum of capital available considerations.

The real criticism of Bierman and Smidt is for their treatment of cash proceeds. In the case of the bridge and the ferry they would reinvest the ferry proceeds at the cost of capital rate until the period of time considered was equal to the longer bridge project life. In a contrived situation this reverses the apparent preference for the short-lived project. That is, the ferry with cash proceeds reinvested at the cost of capital rate has a lower over-all rate of return than the bridge, although the ferry alone has a higher rate of return. Three comments may be made on this. First, it is not always possible to estimate future revenues accurately so we will make conservative adjustments. These tend to affect short and long-lived projects differently. Secondly, there is an average rate of return, higher than the cost of

capital, which would more correctly reflect the value of cash proceeds in the extension of a short-lived project for rate of return analysis purposes. Thirdly, we should not overlook the case for extending the cash proceeds of a short project at the same rate as its so-called long-lived alternative.

Looking over our shoulder it appears that rate of return has some "bugs" in it and these are known by quite a few people. Bierman and Smidt may have summarized the more important problems; at least they haven't found any new ones. The "bugs" Bierman and Smidt and others have written of may make rate of return less useful than some people contend it is, but, on the other hand, it may still be better than the capital budgeting analysis your firm is now using.

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Review

APPRAISING THE ECONOMICS OF ELECTRONIC COMPUTERS *

There is, presently, considerable confusion concerning the economic appraisal of electronic computers for business use. Some authorities have cited many cases of significant savings following the business use of computers, while others declare that there are as yet no successful commercial applications. Perhaps these contrary estimates stem from the differences in what is meant by the economic appraisal of an electronic computer.

Business computers have been acquired on all the grounds that include and lie between reason and fancy. Some companies have purchased or rented computers for their show value; others have fallen in line so as not to "fall behind"; and still others have given in to the urge in order to secure hitherto unattainable information or to make practicable large scale use of operations research techniques. By far the majority have justified their computers on the ground of reduced clerical costs. Regardless, each decision to obtain a computer can be looked upon as the result of an economic appraisal - if not in terms of dollar value, then on some other utilitarian scale. This leads us to the book under review: "Appraising the Economics of Electronic Computers".

Although the author of this report disclaims any intention of providing answers to the problems confronting the would-be users

* FRANK WALLACE: Controllership Foundation, Inc., 2 Park Avenue, New York, 1957. 106 pp. $4.

of electronic computers, in their economic appraisal, he has taken a considerable step in this direction through an exhaustive cataloguing of these problems. It would be difficult to find another book on the business uses of computers which packs so much information about their pitfalls and prospects into so few pages. After reading the book one can appreciate the old joke shared by computer people, which defines a computer expert as a man who still has not had his computer installed.

In the author's view, the economic appraisal of an electronic computer must start with the costs of making a feasibility study, then carry over to the costs of the critical period of installation, and finally end with the continuing costs of operating and maintaining the computer. The appraisal is then made on the basis of a comparison of these costs with the costs of the old system.

Aside from the questions of cost, the report first examines the question of how thorough a feasibility study should be. Then, assuming that we have made the big decision to launch such a study, we are confronted with the problems of organizing the computer feasibility team regarding its size, selection, training and supervision, its communication problems, and its need for consulting help. Having set up the team we are then introduced to the problems and criteria for selecting the areas for specific study. Once in these areas we thread through the present procedures, bringing projected computer systems to bear on these areas, so as to be in a position to determine the costs involved.

The author does not leave us at the end of the feasibility study but stays with us through the critical period of installation,

where everything we have failed to foresee crops up to taunt our estimates. Finally we receive an extensive coverage of what goes into the operation and maintenance of a computer. For good measure there are appendices on how a computer works, computer applications, a summary of equipment and operations research. The book also contains many useful exhibits, such as "Clerical Salaries by Function and Location", "Typical Electronic Computer Annual Operating Costs", and "Typical Personnel Costs to Operate a Computer".

There is something in this book to buttress every view on appraising the economics of computers, even though it may be but a word, a sentence, or a paragraph. However, the author avoids the subject of evaluations of intangibles such as new data possibilities or new analytical techniques, and devotes most of his effort to costing out of such tangible items as human and machine costs and those supporting items which can easily be price-tagged. The reviewer feels that all of this study of tangible items may be necessary, yet he personally would place considerably more stress on the so-called intangibles. Before directing attention to matters of a tangible character, he would suggest an examination of the management of the organization and its objectives. It hardly would be worthwhile to install a computer for an organization operating under ineffective management, since this could lead only to a magnification of difficulties.

The author has paid scant attention to the area of management objectives, perhaps because it is out-of-bounds for the feasibility team. Still, the final decision on acquiring a computer lies, not

with the feasibility team, but with management. In making its decision, management must consider that the purpose of a data processing system is not to produce paper but information, of a kind which helps to promote the objectives of the organization. Unfortunately, few firms have clearly thought out or formalized their objectives, or specified their information requirements in these terms.

The computer study should be the justification for studies in this neglected area, so that if and when a computer system is acquired, its real economies can be realized in its ability to provide the timely control information with which the company can develop true diagnosticians in management rather than post-mortem experts.

Irving M. Jasphy

Stevens Institute of Technology

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INTERNAL REVENUE - DEPRECIATION REGULATIONS

Regulations relating to depreciation, referred to as Treasury Decision 6182, are again available in limited quantity from the Superintendent of Documents, United States Government Printing Office, Washington, D. C., for 20¢ each (Code Number T22.19 : D44/957). These regulations are a part of the Income Tax Regulations issued under the Internal Revenue Code of 1954 and are a handy reference source totalling only thirty-four pages, including a complete index. The Table of Contents, restricted to subject matter only, follows:

Statutory provisions; depreciation; general rule.
Depreciation in general.
Tangible property.
Intangibles.
Leased property.
Apportionment of basis.
Depreciation in special cases.
Accounting for depreciable property.
Retirements.
Obsolescence.
When depreciation deduction is allowable.
Statutory provisions; depreciation; use of certain methods and rates.
Methods of computing depreciation.
Straight line method.
Declining balance method.
Sum of the years-digits method.[1]
Other methods.
Statutory provisions; depreciation; limitations on use of certain methods and rates.
Limitations on methods of computing depreciation under section 167(b) (2), (3) and (4).
Statutory provisions; depreciation; agreement as to useful life on which depreciation is based.
Agreement as to useful life and rates of depreciation.
Statutory provisions; depreciation; change in method.
Change in method.
Statutory provisions; depreciation; basis for depreciation.
Basis for depreciation.

[1] Includes Table of Decimal Equivalent for Use of Sum of the Years-Digits Method, Based on Remaining Life.

Statutory provisions; depreciation; life tenants and beneficiaries of trusts and estates.
Life tenants and beneficiaries of trusts and estates.
Statutory provisions; depreciation; depreciation of improvements in the case of mines, etc.
Depreciation of improvements in the case of mines, etc.

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